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NASA Contractor Report 4755

Real-Gas Flow Properties for NASA Langley Research Center Aerothermodynamic Facilities Complex Wind Tunnels

Brian R. Hollis

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ACKNOWLEDGEMENTS

This research was supported by grants NAGW-1331 and NAG-1-1663 to the North Carolina State University Mars Mission Research Center.

ABSTRACT

A computational algorithm has been developed which can be employed to determine the flow properties of an arbitrary real (virial) gas in a wind tunnel. A multiple-coefficient virial gas equation of state and the assumption of isentropic flow are used to model the gas and to compute flow properties throughout the wind tunnel. This algorithm has been used to calculate flow properties for the wind tunnels of the Aerothermodynamic Facilities Complex at the NASA Langley Research Center, in which air, CF_4, He, and N_2 are employed as test gases. The algorithm is detailed in this paper and sample results are presented for each of the Aerothermodynamic Facilities Complex wind tunnels.

SYMBOLS

A_i	correction factor defined by Eq. (31)
a	sonic speed (m/sec)
$b_{i,j}$	virial coefficient in Eq. (2)
e	internal energy (J/kg)
c_p	specific heat at constant pressure (J/kg-K)
c_v	specific heat at constant volume (J/kg-K)
h	enthalpy (J/kg)
k	thermal conductivity (W/m-K)
M	Mach number, u/a
p	pressure (Pa)
Pr	Prandtl number, $\mu c_p/k$
q	dynamic pressure (Pa)
R	gas constant (kJ/kg-K)
Re	Reynolds number, $\rho uL/\mu$
s	entropy (J/kg-K)
T	temperature (K)
T^{ε}	attraction energy (K)
u	velocity (m/sec)
W	molar mass g/g-mol
Z	compressibility factor
α_j	polynomial coefficient in Eq. (24)

β_j	polynomial coefficient in Eq. (24)
Δ_1	integration constant defined in Eq. (27)
Δ_2	integration constant defined in Eq. (28)
$\Delta h_{f,0}$	enthalpy of sublimation at 0 K, (J/kg)
$\Delta s_{f,0}$	entropy of sublimation at 0 K, (J/kg-K)
ϕ	non-dimensional temperature, T / T_{ref}
γ	specific heat ratio
μ	viscosity, kg/m-sec
$\Omega^{(2,2)*}$	collision integral for viscosity
σ	collision cross-section (Å)
ρ	density (kg/m^3)
τ	non-dimensional temperature, T / T_{CR}
ω	non-dimensional density, ρ / ρ_{CR}
ω^*	non-dimensional density, $p_{ST} / (\rho_{CR} RT)$

SUBSCRIPTS AND SUPERSCRIPTS

CR	critical point
ref	reference condition (100 K at 1 atmosphere)
ST	standard point pressure (1 atmosphere)
x	arbitrary point
0	stagnation (subscript)
0	"zero-pressure" value (superscript)
1	freestream
2	post-shock static
0,1	reservoir stagnation
0,2	post-shock stagnation (pitot)

INTRODUCTION

Conventional subsonic aerospace vehicles generally remain in a flight regime in which the flow around the vehicle can be treated as that of a **calorically perfect gas**; that is, the perfect gas equation of state is valid, and the specific heats, c_p and c_v, are constants. Supersonic vehicles reach flight regimes in which the calorically perfect model is no longer valid due to equilibrium vibrational excitation of the gas, and the flow must be treated as that of a **thermally perfect gas**. The perfect gas equation of state still holds in this case, but the specific heats must be treated as functions of temperature. In the **high temperature gas** flight regime of hypersonic vehicles, chemical reactions and non-equilibrium vibrational excitation of the gas occur, and the thermodynamic properties are then functions of both temperature and pressure. However, for each of the *individual* species of the gas, the thermally perfect gas model is still valid. It is the modeling of these three regimes, the calorically perfect gas, the thermally perfect gas, and the high temperature gas, with which most aerospace research is concerned, as they are the actual flight regimes of aerospace vehicles. However, in the wind tunnel testing which is required as part of the design and development of new aerospace vehicles, a fourth regime, that of the **real gas**, becomes important. Real gas flows are high density flows in which the intermolecular forces acting between the molecules of the gas cannot be neglected. In a real gas, the specific heats and other thermodynamic properties are functions of both temperature and density, and, most importantly, the perfect gas equation of state is no longer valid.

In the idealized model of a conventional wind tunnel, the high velocities of atmospheric flight are simulated by allowing a highly pressurized gas (which may also be heated) to isentropically expand from a reservoir through a nozzle to a lower pressure and temperature in a test section. During this expansion, the total enthalpy of the gas remains constant, and thus a high-velocity flow is produced in the test section of the wind tunnel. It is in the reservoir of the wind tunnel (and to a lesser extent behind any shock wave created by a model being tested in the wind tunnel) that a very high density, which leads to real gas behavior, is produced. Because the test-section flow conditions are dependent on the initial state of the gas in the reservoir (as well as the expansion process through the nozzle), it is important to correctly model this real gas behavior so that the test-section conditions can be computed and the test data may be properly interpreted.

To fulfill this need, the ***GASPROPS*** (short for Gas Properties) algorithm has been developed. ***GASPROPS*** is an algorithm which can be used to model the flow of any arbitrary real gas in a wind tunnel. In this algorithm, the common assumptions that the expansion process is isentropic and adiabatic, and in vibrational equilibrium, are made. However, at all points in the wind tunnel, the flow is modeled using a real gas, multiple-coefficient virial equation of state.

GASPROPS has been developed specifically with the wind tunnels of the Aerothermodynamic Facilities Complex at the NASA Langley Research Center (Micol, Ref. 1) in mind. These facilities are: the 31-Inch Mach 10 Air Tunnel, the 20-Inch Mach 6 Air Tunnel, the 15-Inch Mach 6 High Temperature Air Tunnel, the 20-Inch Mach 6 CF_4 Tunnel, the 20-Inch Mach 17 N_2 Tunnel, and the 22-Inch Mach 20 He Tunnel. The equation of state coefficient data for the test gases used in these tunnels, air, CF_4, He and N_2, is included in this report. The algorithm, however, can be used for any gas for which coefficient data are supplied.

THE *GASPROPS* ALGORITHM

Formulas for Thermodynamic Properties

The basis of the *GASPROPS* algorithm is a multiple-coefficient virial equation of state for an arbitrary gas, as given by:

$$p = Z\rho R T \tag{1}$$

The compressibility factor in the equation of state is given by:

$$Z = 1 + \sum_{i=1}^{r} \sum_{j=0}^{s_i} b_{i,j} \left(\frac{\omega^i}{\tau^j}\right) \tag{2}$$

where the gas temperature and density are non-dimensionalized by their critical point values as :

$$\omega = \rho / \rho_{CR} \tag{3}$$

$$\tau = T / T_{CR} \tag{4}$$

Values of the $b_{i,j}$ coefficients for the gases of interest have been compiled by Sychev et al (Refs. 2-5), and are tabulated in the Appendix in Tables I-1 through I-4. (These references should be examined carefully as several errors in the equations were introduced in their translation to English). Data are also available for additional gases from other volumes in this series.

In order to compute the flow properties throughout a wind tunnel, it is assumed that the gas undergoes an isentropic expansion from the tunnel reservoir to the test section. Therefore, the total enthalpy and entropy of the gas are conserved. In the absence of chemical reactions, the enthalpy and entropy, as well as all of the other thermodynamic properties of a gas can be defined in terms of two independent, intrinsic properties. In this case, the properties used will be the density and temperature of the gas, because these are the properties used in the definition of the compressibility factor in Eq. (2). Generalized equations for enthalpy and entropy are developed beginning from the definitions for the differentials of enthalpy and entropy in terms of density and temperature:

$$dh = \left(\frac{\partial h}{\partial T}\right)_{\rho} dT + \left(\frac{\partial h}{\partial \rho}\right)_{T} d\rho \tag{5}$$

$$ds = \left(\frac{\partial s}{\partial T}\right)_\rho dT + \left(\frac{\partial s}{\partial \rho}\right)_T d\rho \tag{6}$$

The Gibbsian equations for a simple compressible substance in equilibrium will also be required:

$$dh = Tds + \frac{1}{\rho}dp \tag{7}$$

$$ds = \frac{1}{T}de - \frac{p}{\rho^2 T}d\rho \tag{8}$$

Eqs. (7) and (8) can then be expanded using the chain rule to obtain expressions in the forms of Eqs. (5) and (6):

$$dh = \left[T\left(\frac{\partial s}{\partial T}\right)_\rho + \frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_\rho\right]dT + \left[T\left(\frac{\partial s}{\partial \rho}\right)_T + \frac{1}{\rho}\left(\frac{\partial p}{\partial \rho}\right)_T\right]d\rho \tag{9}$$

$$ds = \left[\frac{1}{T}\left(\frac{\partial e}{\partial T}\right)_\rho\right]dT + \left[\frac{1}{T}\left(\frac{\partial e}{\partial \rho}\right)_T - \frac{p}{\rho^2 T}\right]d\rho \tag{10}$$

It is now necessary to develop relationships for the partial derivatives in Eqs. (9) and (10). The second and fourth partial derivatives in Eq. (9) can be defined using Eqs. (1) and (2). Next, by comparing Eqs. (6) and (10), it can be seen that the first partial derivative in Eq. (9) can be replaced by:

$$T\left(\frac{\partial s}{\partial T}\right)_\rho = \left(\frac{\partial e}{\partial T}\right)_\rho \equiv c_v \tag{11}$$

At this point, introduce a third Gibbsian equation which is in terms of the Helmholtz function, w:

$$dw = \frac{p}{\rho^2}d\rho - sdT \tag{12}$$

From Eq. (12), it can be seen that:

$$\left(\frac{\partial w}{\partial \rho}\right)_T = \frac{p}{\rho^2} \tag{13a}$$

and:

$$\left(\frac{\partial w}{\partial T}\right)_\rho = -s \tag{13b}$$

As the order of differentiation of partial differentiation does not affect the final result, Eqs. (13a) and (13b) can be used to produce one of the Maxwell relations:

$$\left[\frac{\partial}{\partial T}\left(\frac{\partial w}{\partial \rho}\right)_T\right]_\rho = \frac{\partial}{\partial T}\left(\frac{p}{\rho^2}\right)_\rho = \left[\frac{\partial}{\partial \rho}\left(\frac{\partial w}{\partial T}\right)_\rho\right]_T = -\left(\frac{\partial s}{\partial \rho}\right)_T \tag{14}$$

Eq. (14) defines the third partial derivative in equation (9). Substitution of equations (11) and (14) into (9) leads to:

$$dh = \left[c_v + \frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_\rho\right]dT + \left[-\frac{T}{\rho^2}\left(\frac{\partial p}{\partial T}\right)_\rho + \frac{1}{\rho}\left(\frac{\partial p}{\partial \rho}\right)_T\right]d\rho \tag{15}$$

Finally, a relationship for the second partial derivative in Eq. (10) can be derived by introducing the definition:

$$h \equiv e + \frac{p}{\rho} \tag{16}$$

Taking the differential of Eq. (16) with respect to density and temperature gives:

$$de = \left[\left(\frac{\partial h}{\partial T}\right)_\rho - \frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_\rho\right]dT + \left[\left(\frac{\partial h}{\partial \rho}\right)_T - \frac{1}{\rho}\left(\frac{\partial p}{\partial \rho}\right)_T + \frac{p}{\rho^2}\right]d\rho \tag{17}$$

Then, from Eqs. (15) and (17):

$$\left(\frac{\partial e}{\partial \rho}\right)_T = \frac{-T}{\rho^2}\left(\frac{\partial p}{\partial T}\right)_\rho + \frac{p}{\rho^2} \tag{18}$$

Substitution of Eqs. (11) and (18) into (10) leads to:

$$ds = \frac{c_v}{T}dT - \frac{1}{\rho^2}\left(\frac{\partial p}{\partial T}\right)_\rho d\rho \tag{19}$$

Since both enthalpy and entropy are point functions, Eqs. (15) and (19) can be integrated along any path to obtain the same result. Therefore, these equations are integrated from a reference point to the required temperature and density in two steps; first along a constant density path to the desired temperature, and then along a constant temperature path to the desired density:

$$h(T,\rho) = \Delta_1 + \int_T \left(\frac{\partial h}{\partial T}\right)_\rho dT + \int_\rho \left(\frac{\partial h}{\partial \rho}\right)_T d\rho \tag{20}$$

$$s(T,\rho) = \Delta_2 + \int_T \left(\frac{\partial s}{\partial T}\right)_\rho dT + \int_\rho \left(\frac{\partial s}{\partial \rho}\right)_T d\rho \tag{21}$$

The arbitrary reference point is defined to be at a sufficiently low density that the perfect gas equation of state is valid during the integration over temperature. For the data from Refs. (2-5), the chosen reference point is T_{ref} = 100 K at one atmosphere. Because of this, Eqs. (15) and (19) can be simplified to their perfect-gas equivalents when computing the integration constants Δ_1 and Δ_2 :

$$h(T_{ref},\rho_{ref}) = h_{ref} + \Delta h_{f,0} = \int_T c_p^0 dT \,\Big|_{T_{ref},\rho_{ref}} + \Delta_1 \tag{22}$$

$$s(T_{ref},\, \rho_{ref}) = s_{ref} + \Delta s_{f,0} = \int_T \left(\frac{c_p^0}{T} - \frac{R}{T}\right) dT \,\Big|_{T_{ref},\rho_{ref}} - \int_\rho \left(\frac{R}{\rho}\right) d\rho \Big|_{T_{ref},\rho_{ref}} + \Delta_2 \tag{23}$$

where $\Delta h_{f,0}$ and $\Delta s_{f,0}$ are the enthalpy and entropy of sublimation at 0 K, and h_{ref} and s_{ref} are the enthalpy and entropy at the reference point (100 K at 1 atm). These values are given in the Appendix in Table I-5.

Because of the low density at the reference point, the specific heat can be represented by its "zero-pressure" (i.e. temperature-dependent only) value. The zero-pressure specific heat is calculated from curve fits to tabular data given by Hilsenrath et al in Ref. (6). The curve fit coefficients are taken from Refs. (2-5), and the equation for zero-pressure specific heat has the form:

$$c_p^0 = R\left[\sum_{j=0}^{m} \alpha_j \phi^{j} + \sum_{j=1}^{n} \beta_j \phi^{-j}\right] \tag{24a}$$

where:

$$\phi = \frac{T}{T_{ref}} \tag{24b}$$

Values of the indices, m and n, and the curve fit coefficients, α_j and β_j, are given in the Appendix in Tables I–6 and I–7. Substituting Eq. (24a) into the integral terms in Eqs. (22) and (23) leads to:

$$\int_T c_p^0\, dT = \left[\sum_{j=0}^{m} \frac{\alpha_j}{j+1}\phi^{j} - \sum_{j=2}^{n} \frac{\beta_j}{j-1}\phi^{-j} + \frac{1}{\phi}\beta_1 lnT\right] RT \equiv h^0 \tag{25}$$

and:

$$\int_T \left(\frac{c_p^0}{T} - \frac{R}{T}\right) dT - \int_\rho \frac{R}{\rho} d\rho = \left[\sum_{j=1}^{m} \frac{\alpha_j}{j}\phi^{j} - \sum_{j=1}^{n} \frac{\beta_j}{j}\phi^{-j} + \alpha_0 lnT - lnT - ln\rho\right] R \equiv s^0 - R ln(\rho T) \tag{26}$$

The integration constants are then:

$$\Delta_1 = \left[\sum_{j=2}^{n} \frac{\beta_j}{j-1} - \sum_{j=0}^{m} \frac{\alpha_j}{j+1} - \beta_1 lnT_{ref}\right] RT_{ref} + \Delta h_{f,0} + h_{ref} \tag{27}$$

and:

$$\Delta_2 = \left[\sum_{j=1}^{n}\frac{\beta_j}{j} - \sum_{j=1}^{m}\frac{\alpha_j}{j} - \alpha_0 lnT_{ref}\right]R + \Delta s_{f,0} + s_{ref} + Rln\left(T_{ref}\rho_{ref}\right) \tag{28}$$

The equations for enthalpy and entropy are now:

$$h(T,\rho) = h^0(T) + \left.\int_{\rho}\left(\frac{\partial h}{\partial \rho}\right)_T d\rho\right|_{T,\rho} \tag{29a}$$

where:

$$h^0(T) = \left[\sum_{j=0}^{m}\frac{\alpha_j}{j+1}\phi^{j} - \sum_{j=2}^{n}\frac{\beta_j}{j-1}\phi^{-j} + \frac{1}{\phi}\beta_1 ln\phi + \frac{1}{\phi}\left(\sum_{j=2}^{n}\frac{\beta_j}{j-1} - \sum_{j=0}^{m}\frac{\alpha_j}{j+1}\right)\right]RT + \Delta h_{f,0} + h_{ref} \tag{29b}$$

and:

$$s(T,\rho) = s^0(T) + Rln\left(\frac{T_{ref}\rho_{ref}}{T}\right) + \left.\int_{\rho}\left(\frac{\partial s}{\partial \rho}\right)_T d\rho\right|_{T,\rho} \tag{30a}$$

where:

$$s^0(T) = \left[\sum_{j=1}^{m}\frac{\alpha_j}{j}\phi^{j} - \sum_{j=1}^{n}\frac{\beta_j}{j}\phi^{-j} + \sum_{j=1}^{n}\frac{\beta_j}{j} - \sum_{j=1}^{m}\frac{\alpha_j}{j} + \alpha_0 ln\phi\right]R + \Delta s_{f,0} + s_{ref} \tag{30b}$$

The integrals over density in Eqs. (29a) and (30a) are functions of the compressibility factor defined in Eq. (2). For these integrals, and for computation of other thermodynamic properties, it will be helpful to introduce the following correction factors as defined in Ref. (2-5):

$$A_0 \equiv \sum_{i=1}^{r}\sum_{j=0}^{s_i} b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31a}$$

$$A_1 \equiv \sum_{i=1}^{r}\sum_{j=0}^{s_i} (i+1)\, b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31b}$$

$$A_2 \equiv -\sum_{i=1}^{r}\sum_{j=0}^{s_i} (j-1)\, b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31c}$$

$$A_3 \equiv \sum_{i=1}^{r}\sum_{j=0}^{s_i} \left(\frac{i+j}{i}\right) b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31d}$$

$$A_4 \equiv \sum_{i=1}^{r}\sum_{j=0}^{s_i} \left(\frac{j-1}{i}\right) b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31e}$$

$$A_5 \equiv -\sum_{i=1}^{r}\sum_{j=0}^{s_i} \left(\frac{j\,(j-1)}{i}\right) b_{i,j}\left(\frac{\omega^i}{\tau^j}\right) \tag{31f}$$

By using Eq. (15), the integrand in Eq. (29a) can be expressed in terms of the compressibility factor as:

$$\left(\frac{\partial h}{\partial \rho}\right)_T = \left[\frac{-T}{\rho^2}\left(\frac{\partial p}{\partial T}\right)_\rho + \frac{1}{\rho}\left(\frac{\partial p}{\partial \rho}\right)_T\right] = RT\left[\frac{-T}{\rho}\left(\frac{\partial Z}{\partial T}\right)_\rho + \left(\frac{\partial Z}{\partial \rho}\right)_T\right] \tag{32}$$

where from Eq. (2):

$$\left(\frac{\partial Z}{\partial T}\right)_\rho = \frac{-1}{T}\sum_{i=1}^{r}\sum_{j=0}^{s_i} j b_{ij}\frac{\omega^i}{\tau^j} \tag{33}$$

and:

$$\left(\frac{\partial Z}{\partial \rho}\right)_T = \frac{1}{\rho}\sum_{i=1}^{r}\sum_{j=0}^{s_i} i b_{ij}\frac{\omega^i}{\tau^j} \tag{34}$$

The integral in Eq. (29a) then becomes:

$$\int_{\rho}\left(\frac{\partial h}{\partial \rho}\right)_T d\rho = RT\int_{\rho}\left(\frac{1}{\rho}\sum_{i=1}^{r}\sum_{j=0}^{s_i}(i+j)b_{i,j}\frac{\omega^i}{\tau^j}\right) = RT\sum_{i=1}^{r}\sum_{j=0}^{s_i}\frac{(i+j)}{i}b_{i,j}\frac{\omega^i}{\tau^j} = RTA_3 \tag{35}$$

and the enthalpy is then given by:

$$h = h^0 + RTA_3 \tag{36}$$

By using Eq. (19), the integrand in Eq. (30a) can be expressed in terms of the compressibility coefficient:

$$\left(\frac{\partial s}{\partial \rho}\right)_T = \frac{-1}{\rho^2}\left(\frac{\partial p}{\partial T}\right)_\rho = \frac{-R}{\rho}\left[Z + T\left(\frac{\partial Z}{\partial T}\right)_\rho\right] \tag{37}$$

The integral in Eq. (30a) is then:

$$\int_{\rho}\left(\frac{\partial s}{\partial \rho}\right)_T d\rho = R\int_{\rho}\left[\frac{1}{\rho}\left(-1 + \sum_{i=1}^{r}\sum_{j=0}^{s_i}(j-1)b_{i,j}\frac{\omega^i}{\tau^j}\right)\right]d\rho = R\left[-ln\rho + \sum_{i=1}^{r}\sum_{j=0}^{s_i}\frac{(j-1)}{i}b_{i,j}\frac{\omega^i}{\tau^j}\right] = -Rln\rho + RA_4 \tag{38}$$

The entropy is then given by:

$$s = s^0 - Rln\left(\frac{\omega}{\omega^*}\right) + RA_4 \tag{39a}$$

where:

$$\frac{\omega}{\omega^*} \equiv \frac{\rho}{\rho_{CR}}\frac{\rho_{CR}RT}{p_{ST}} = \frac{\rho}{\rho_{CR}}\frac{\rho_{CR}RT}{\rho_{ref}RT_{ref}} = \frac{\rho T}{\rho_{ref}T_{ref}} \tag{39b}$$

Eqs. (36) and (39) completely define the enthalpy and entropy of a real gas in terms of temperature and density. Real gas relationships for other thermodynamic properties can be derived in a similar manner (e.g. Wark, Ref. 7).

Compressibility coefficient:

$$Z = 1 + A_0 \tag{40}$$

Internal energy:

$$e = h - ZRT \tag{41}$$

Constant volume specific heat:

$$c_v = c_v^0 + A_5 R \tag{42}$$

Constant pressure specific heat:

$$c_p = c_v + \frac{(1+A_2)^2}{(1+A_1)} R \tag{43}$$

Specific heat ratio:

$$\gamma = \gamma^0 \frac{(1+A_1)}{(1+A_0)} \tag{44a}$$

where:

$$\gamma^0 = \frac{c_p}{c_v} \tag{44b}$$

Sonic speed:

$$a = a^0 \sqrt{1+A_1} \tag{45a}$$

where:

$$a^0 = \sqrt{\gamma^0 R T} \tag{45b}$$

Computation of Wind Tunnel Flow Conditions

With the assumption of isentropic expansion from the reservoir of the tunnel to the test section, the flow properties at any given point in the expansion can be computed through specification of the Mach number at that point. The points of interest are generally the reservoir, where the flow is stagnant, the throat of the tunnel, where the flow is sonic, and the test section of the tunnel, where the Mach number can be determined from a pitot pressure measurement.

Reservoir pressure and temperature are properties normally measured during the operation of a wind tunnel. From these properties, the reservoir density can be computed by Newtonian iteration on the virial equation of state, Eq. (1), where

$$F(\rho_{0,1}{}^n) = \left(p_{0,1}\right)_{measured} - Z_{0,1}\,\rho_{0,1}^n\,R\left(T_{0,1}\right)_{measured} \tag{46a}$$

$$F'(\rho_{0,1}) = -Z_{0,1}R\left(T_{0,1}\right)_{measured} - \omega_{0,1}R\left(T_{0,1}\right)_{measured}\left[\sum_{i=1}^{r}\sum_{j=0}^{s_i} ib_{ij}\frac{\omega_{0,1}^{i-1}}{\left(\tau_{0,1}^{j}\right)_{measured}}\right] \tag{46b}$$

$$\rho_{0,1}^{n+1} = \rho_{0,1}^n - \frac{F(\rho_{0,1}^n)}{F'(\rho_{0,1}^n)} \tag{46c}$$

Note that in these equations, n is the iteration level, not an exponent.

The remaining reservoir properties can then be computed from Eqs. (40) through (45). To compute properties at any other point in the expansion (denoted by subscript x), a Mach number must be specified, and then an iteration on the density and temperature at the point is carried out in order to determine the values which give the same total enthalpy and entropy, which are constants, as computed for the reservoir. At any point in the expansion, the total enthalpy and entropy are given by:

$$\left[h_x^0 + A_3RT_x + \frac{(M_xa_x)^2}{2}\right] = \text{constant} = h_{0,1} \tag{47}$$

$$\left[s_x^0 - ln\left(\frac{\omega_x}{\omega^*}\right)R + A_4R\right] = \text{constant} = s_{0,1} \tag{48}$$

Eqs. (47) and (48) can be used to compute the test section freestream properties in a wind tunnel. However, the freestream Mach number is generally not known, but is determined from a pitot pressure measurement and other flow properties. Therefore, in order to determine the freestream properties, an initial estimate of the Mach number must first be made, and then initial values for the freestream properties are computed based on the assumed Mach number. The density and temperature at the assumed Mach number is computed through vector Newtonian iteration:

$$\vec{G}^{n+1} = \vec{G}^n - \left[\frac{\delta\vec{W}}{\delta\vec{G}}\right]^{-1}\vec{W} \tag{49a}$$

where:

$$\vec{G} = \begin{bmatrix}\rho_1\\ T_1\end{bmatrix} \tag{49b}$$

$$\vec{W} = \begin{bmatrix}w_1\\ w_2\end{bmatrix} \tag{49c}$$

$$\left[\frac{\delta\vec{W}}{\delta\vec{G}}\right] = \begin{bmatrix}\frac{\delta W_1}{\delta G_1} & \frac{\delta W_2}{\delta G_1}\\ \frac{\delta W_1}{\delta G_2} & \frac{\delta W_2}{\delta G_2}\end{bmatrix} \tag{49d}$$

and:

$$w_1 = h_{0,1} - \left[h_1^0 + A_3 R T_1 + \frac{(M_1 a_1)^2}{2} \right] \tag{50a}$$

$$w_2 = s_{0,1} - \left[s_1^0 - ln\left(\frac{\omega_1}{\omega^*}\right) R + A_4 R \right] \tag{50b}$$

(Note that this procedure can be used to compute the flow conditions at any arbitrary point in the wind tunnel as specified by the Mach number. One example would be at the throat of the nozzle, where it is assumed that the Mach number is one).

After computing the test section freestream properties at the assumed Mach number, the test section post-normal-shock static properties can then be computed by iterating on density and temperature to satisfy the conservation of total enthalpy and momentum. Note that in this case, the conservation of entropy as in Eq. (48) is not valid because of the shock wave, and the conservation of total momentum instead becomes the second relationship used in the process of solving for density and temperature. The iteration for density and temperature at this point is as follows:

$$\vec{G}^{n+1} = \vec{G}^n - \left[\frac{\delta \vec{W}}{\delta \vec{G}} \right]^{-1} \vec{W} \tag{51a}$$

where

$$\vec{G} = \begin{bmatrix} \rho_2 \\ T_2 \end{bmatrix} \tag{51b}$$

$$\vec{W} = \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \tag{51c}$$

$$\left[\frac{\delta \vec{W}}{\delta \vec{G}} \right] = \begin{bmatrix} \dfrac{\delta W_1}{\delta G_1} & \dfrac{\delta W_2}{\delta G_1} \\ \dfrac{\delta W_1}{\delta G_2} & \dfrac{\delta W_2}{\delta G_2} \end{bmatrix} \tag{51d}$$

and:

$$w_1 = h_{0,1} - \left[h_2^0 + A_3RT_2 + \frac{(M_2a_2)^2}{2}\right] \tag{52a}$$

$$w_2 = \left(p_1 + \rho_1u_1^2\right) - \left(p_2 + \rho_2u_2^2\right) \tag{52b}$$

Finally, the post-normal-shock stagnation conditions (pitot conditions) are computed by iteration on density and temperature to satisfy conservation of total enthalpy and entropy:

$$\vec{G}^{n+1} = \vec{G}^n - \left[\frac{\delta\vec{W}}{\delta\vec{G}}\right]^{-1}\vec{W} \tag{53a}$$

$$\vec{G} = \begin{bmatrix}\rho_{0,2}\\ T_{0,2}\end{bmatrix} \tag{53b}$$

$$\vec{W} = \begin{bmatrix}w_1\\ w_2\end{bmatrix} \tag{53c}$$

$$\left[\frac{\delta\vec{W}}{\delta\vec{G}}\right] = \begin{bmatrix}\frac{\delta W_1}{\delta G_1} & \frac{\delta W_2}{\delta G_l}\\ \frac{\delta W_1}{\delta G_2} & \frac{\delta W_2}{\delta G_2}\end{bmatrix} \tag{53d}$$

$$w_1 = h_{0,1} - \left[h_{0,2}^0 + A_3RT_{0,2}\right] \tag{54a}$$

$$w_2 = s_2 - \left[s_{0,2}^0 - ln\left(\frac{\omega_{0,2}}{\omega^*}\right)R + A_4R\right] \tag{54b}$$

At this point, the computed post-normal-shock pressure is compared to the measured pitot pressure, and a new estimate for the freestream Mach number is made by Newtonian iteration:

$$M_1^{n+1} = M_1^n - \frac{F(M_1^n)}{F'(M_1^n)} \tag{55a}$$

where:

$$F(M_1^n) = \left(p_{0,2}\right)_{calculated} - \left(p_{0,2}\right)_{measured} \tag{55b}$$

For simplicity the functional derivative is evaluated numerically as:

$$F'(M_1^n) = \frac{\partial\left(p_{0,2}\right)_{calc}}{\partial M_1} \cong \frac{\left(\Delta p_{0,2}\right)_{calc}}{\Delta M_1} = \frac{p_{0,2}(M_1^n + \Delta M_1) - p_{0,2}(M_1^n)}{\Delta M_1^n} \tag{55c}$$

where ΔM_1 is an arbitrary small fraction of M_1.

This sequence of iterations on the freestream, post-shock and pitot conditions is repeated under the computed and measured pitot pressures are in agreement. This typically requires fewer than ten iterations. At this point, the thermodynamic properties have been defined at all points of interest in the wind tunnel.

Transport Properties

The transport properties of air and N_2 in a wind tunnel can be computed from simple kinetic theory models. The viscosity is given by the Chapman-Cowling relation (Ref. 8):

$$\mu = 2.6693 \cdot 10^{-6} \frac{\sqrt{MT}}{\sigma^2 \Omega^{(2,2)*}} \left(\frac{kg}{m-s}\right) \tag{56}$$

Collision diameter values are taken from Ref. 9, and the collision integrals are computed using curve fits for the Lennard-Jones (12-6) potential given in Ref. 10:

$$\begin{aligned}\Omega^{(2,2)*} = {} & \left(1.16145/T^{*0.14874}\right) + \left(0.52487/\exp\left(0.77320 \cdot T^*\right)\right) + \left(2.16178/\exp\left(2.43787 \cdot T^*\right)\right) \\ & - 6.435 \cdot 10^{-4} \cdot T^{*0.14874} \sin\left(18.0323 \cdot T^{*(-0.76830)} - 7.27371\right)\end{aligned} \tag{57a}$$

where:

$$T^{*} = T/T^{\varepsilon} \tag{57b}$$

The thermal conductivities can also computed from kinetic theory models (Ref. 9). For polyatomic gases, the kinetic theory expression with the modified Eucken correction is:

$$k = \mu\left(\frac{15}{4} - 1.32\left(\frac{c_p}{R} - \frac{5}{2}\right)\right)R \tag{58}$$

Note that the above formulation for thermal conductivity is known to be slightly inaccurate at low to moderate temperatures (Ref. 9). Curve fits from experimental data should be used instead if high accuracy is required in the conductivity computation. However, as the other thermodynamic properties computations are independent of the conductivity computations (with the exception of the Prandtl number), this is not necessary in the present work.

In a hypersonic helium wind tunnel, the gas temperature can be less than 10 K in the test section. At temperatures this low, quantum mechanical effects become significant for helium and the simple kinetic theory models are no longer valid. For helium, the curve fits from Maddalon and Jackson (Ref. 11) should be used for viscosity and thermal conductivity

Viscosity:

<u>T < 1.2 K</u>

$$\mu = (2.1630 - 26.665\cdot T + 120.54\cdot T^2 - 187.41\cdot T^3 + 126.82\cdot T^4 - 31.823\cdot T^5)\cdot 10^{-7}\left(\frac{\text{kg}}{\text{m}-\text{sec}}\right) \tag{59a}$$

<u>1.2 K < T < 3.6 K</u>

$$\mu = (5.02 - 3.2241\cdot T + 2.0308\cdot T^2 - 0.22351\cdot T^3)\cdot 10^{-7}\left(\frac{\text{kg}}{\text{m}-\text{sec}}\right) \tag{59b}$$

<u>3.6 K < T < 10.0 K</u>

$$\mu=(-1.5691 + 3.4167 \cdot T - 0.10317 \cdot T^2) \cdot 10^{-7} \left(\frac{\text{kg}}{\text{m-sec}}\right) \tag{59c}$$

<u>$T > 10.0$ K</u>

$$\mu = 5.023 \cdot 10^{-7} \cdot T^{0.647} \left(\frac{\text{kg}}{\text{m-sec}}\right) \tag{59d}$$

Thermal Conductivity:

<u>$T < 1.2$ K</u>

$$k = (-0.68450 - 0.54637 \cdot T + 48.304 \cdot T^2 - 63.865 \cdot T^3 + 23.701 \cdot T^4) \cdot 4.1868 \cdot 10^{-4} \left(\frac{\text{J}}{\text{kg-K}}\right) \tag{60a}$$

<u>1.2 K $< T <$ 3.6 K</u>

$$k = (10.147 - 6.9399 \cdot T + 4.1353 \cdot T^2 - 0.45929 \cdot T^3) \cdot 4.1868 \cdot 10^{-4} \left(\frac{\text{J}}{\text{kg-K}}\right) \tag{60b}$$

<u>3.6 K $< T <$ 10.0 K</u>

$$k=(-2.9384 + 6.3590 \cdot T - 0.19038 \cdot T^2) \cdot 4.1868 \cdot 10^{-4} \left(\frac{\text{J}}{\text{kg-K}}\right) \tag{60c}$$

<u>$T > 10.0$ K</u>

$$k = (5.023 \cdot 10^{-7} \cdot T^{0.647}) \frac{15}{4} R \left(\frac{\text{J}}{\text{kg-K}}\right) \tag{60d}$$

For the polyatomic gas CF_4, the thermal conductivity can be computed from Eq. (58), while the Sutherland formulation for viscosity from Sutton (Ref. 12), which is fitted to experimental data, should be used:

$$\mu = \frac{1.6112 \cdot 10^{-6} \cdot T^{3/2}}{T + 181.1} \left(\frac{\text{kg}}{\text{m-s}}\right) \tag{61}$$

The above information on transport properties is presented only for the sake of convenience in the computation of test section transport properties values. Caution should be exercised in the use of these expressions as they do not take into account real gas effects. This is generally not a concern since the transport properties are not involved in the overall procedure for determining the wind tunnel thermodynamic flow properties. In a wind tunnel test section, there is generally very little deviation from perfect behavior and so these expressions can be safely employed in the computation of freestream transport properties.

SAMPLE RESULTS

The ***GASPROPS*** algorithm has been used to compute flow conditions for each of the wind tunnels in the Aerothermodynamics Facilities Complex (AFC). These flow conditions are given in Tables 1-3 for the 31-Inch Mach 10 Air Tunnel, Tables 4-9 for the 20-Inch Mach 6 Air Tunnel, Tables 10-14 for the 15-Inch Mach 6 High Temperature Air Tunnel, Tables 15-21 for the 20-Inch Mach 6 CF_4 Tunnel, and Tables 22-27 for the 20-Inch Mach 6 Helium Tunnel. The 20-Inch Mach 17 N_2 Tunnel is currently being fitted with a new nozzle (Ref. 1), and thus the new operating points are not yet known. The data presented in the these tables represent the normal operating points for these tunnels, which are the points for which extensive calibrations (Ref. 1) have been conducted.

In each of Tables 1-27, conditions are listed for the tunnel reservoir, test section freestream, behind a normal shock in the freestream, and at stagnation behind a normal shock (pitot condition) in the freestream. For ease of use, the tables list conditions in both SI and English units. In order to conform to standard practice for the AFC wind tunnels, in which the enthalpy is referenced to a value of zero at 0 K, enthalpies are given as $h - \Delta h_{f,0}$. However, because of the real gas correction factor, A_3, which appears in Eq. (36), the value of $h - \Delta h_{f,0}$ at a given temperature will be close but not identical to the enthalpy found in standard thermodynamic tables such as those of McBride, Gordon and Reno (Ref. 13). An exact correspondence with Ref. 13 enthalpy values is given by the quantity $h - \Delta h_{f,0} - A_3$.

CONCLUDING REMARKS

A computational algorithm entitled **GASPROPS** has been developed which can be used to determine the wind tunnel flow properties of an arbitrary real gas. Coefficient data for air, CF_4, He and N_2 is presented in this paper, but the algorithm can be employed to compute flow properties of any gas for which coefficient data are supplied. The algorithm is based on a multiple-coefficient virial equation of state, and the assumption of isentropic expansion from a tunnel reservoir to its test section. The algorithm is an iterative procedure which requires the measurement of the reservoir pressure and temperature and the test section pitot pressure. **GASPROPS** has been used to compute flow properties at the normal operating points of the wind tunnels in the Aerothermodynamic Facilities Complex at the NASA Langley Research Center, and the results are tabulated in this report.

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TABLE 1. 31-Inch Mach 10 Air Tunnel: $Re_1 = 0.5 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
2.4821E+06	9.9833E+02	8.5926E+00	1.0080E+00	1.0461E+06	7.2115E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	(slug/ft^3)		(BTU/lbm)	(BTU/lbm-°R)
3.6000E+02	1.7970E+03	1.6672E-02	1.0080E+00	4.4970E+02	1.7224E+00

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
6.9099E+01	5.2524E+01	4.5846E-03	5.2302E+04	1.4529E+02	1.4098E+03
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.0022E-02	9.4544E+01	8.8956E-06	2.2485E+01	4.7666E+02	4.6253E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
1.7235E+06	4.5560E+03	3.7502E-06	9.7035E+00	1.4000E+00	9.9964E-01
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
5.2531E+05	6.6079E-01	6.7602E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
7.6533E+03	9.7504E+02	2.7343E-02	1.0181E+06	6.1197E+02	2.3638E+02
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.1100E+00	1.7551E+03	5.3054E-05	4.3769E+02	2.0078E+03	7.7552E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
1.5798E+05	7.6390E+02	4.0912E-05	3.8626E-01	1.3380E+00	1.0000E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
4.8153E+04	1.1079E-01	7.3748E-09	6.9751E-01	5.9641E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
8.4461E+03	9.9957E+02	2.9435E-02	1.0461E+06	8.8452E+03	4.1578E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
1.2250E+00	1.7992E+03	5.7113E-05	4.4970E+02	2.1125E+00	7.4949E-09

TABLE 2. 31-Inch Mach 10 Air Tunnel: $Re_1 = 1.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
4.9643E+06	1.0056E+03	1.6928E+01	1.0160E+00	1.0558E+06	7.0199E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
7.2000E+02	1.8100E+03	3.2845E-02	1.0160E+00	4.5389E+02	1.6766E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.2770E+02	5.1772E+01	8.5993E-03	5.1501E+04	1.4424E+02	1.4172E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.8522E-02	9.3190E+01	1.6685E-05	2.2141E+01	4.7324E+02	4.6498E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
3.2974E+06	8.6362E+03	3.6961E-06	9.8254E+00	1.4000E+00	9.9925E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.0050E+06	1.2526E+00	6.6625E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.4510E+04	9.8344E+02	5.1397E-02	1.0277E+06	6.1446E+02	2.3712E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
2.1045E+00	1.7702E+03	9.9726E-05	4.4180E+02	2.0160E+03	7.7795E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
2.9622E+05	1.4449E+03	4.1142E-05	3.8590E-01	1.3373E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
9.0289E+04	2.0957E-01	7.4162E-09	6.9759E-01	5.9769E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.6010E+04	1.0081E+03	5.5322E-02	1.0558E+06	8.6713E+03	4.1809E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
2.3220E+00	1.8146E+03	1.0734E-04	4.5389E+02	2.0710E+00	7.5365E-09

TABLE 3. 31-Inch Mach 10 Air Tunnel: $Re_1 = 2.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0} - \Delta H_{F,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
9.9975E+06	9.9722E+02	3.3822E+01	1.0326E+00	1.0493E+06	6.8078E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.4500E+03	1.7950E+03	6.5626E-02	1.0326E+00	4.5109E+02	1.6259E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
2.3951E+02	5.0274E+01	1.6626E-02	4.9878E+04	1.4214E+02	1.4138E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
3.4738E-02	9.0493E+01	3.2260E-05	2.1443E+01	4.6634E+02	4.6384E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
6.5517E+06	1.6616E+04	3.5878E-06	9.9464E+00	1.4000E+00	9.9821E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.9970E+06	2.4100E+00	6.4673E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.7916E+04	9.7787E+02	9.9441E-02	1.0213E+06	6.1285E+02	2.3638E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
4.0488E+00	1.7602E+03	1.9295E-04	4.3908E+02	2.0107E+03	7.7553E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.7348E+05	2.7782E+03	4.0989E-05	3.8571E-01	1.3378E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.7480E+05	4.0295E-01	7.3887E-09	6.9754E-01	5.9810E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
3.0799E+04	1.0024E+03	1.0703E-01	1.0493E+06	8.4770E+03	4.1654E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
4.4670E+00	1.8043E+03	2.0767E-04	4.5109E+02	2.0246E+00	7.5086E-09

TABLE 4. 20-Inch Mach 6 Air Tunnel: $Re_1 = 0.5 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
2.0684E+05	4.8333E+02	1.4898E+00	1.0007E+00	4.8617E+05	7.1439E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	(slug/ft^3)		(BTU/lbm)	(BTU/lbm-°R)
3.0000E+01	8.7000E+02	2.8907E-03	1.0007E+00	2.0901E+02	1.7062E+00

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.4515E+02	6.0710E+01	8.3312E-03	6.0521E+04	1.5620E+02	9.2266E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
2.1052E-02	1.0928E+02	1.6165E-05	2.6018E+01	5.1246E+02	3.0271E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
1.7667E+06	3.5461E+03	4.3511E-06	5.9069E+00	1.4000E+00	9.9974E-01
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
5.3848E+05	5.1432E-01	7.8432E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
5.8889E+03	4.6820E+02	4.3815E-02	4.7078E+05	4.3218E+02	1.7544E+02
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
8.5411E-01	8.4277E+02	8.5015E-05	2.0239E+02	1.4179E+03	5.7558E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
3.0527E+05	6.7428E+02	2.5181E-05	4.0594E-01	1.3897E+00	1.0000E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
9.3046E+04	9.7795E-02	4.5391E-09	6.9148E-01	5.2592E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
6.5914E+03	4.8322E+02	4.7519E-02	4.8617E+05	8.1334E+03	2.5728E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
9.5600E-01	8.6979E+02	9.2201E-05	2.0901E+02	1.9425E+00	4.6378E-09

TABLE 5. 20-Inch Mach 6 Air Tunnel: Re_1 = 1.0 x 10^6 per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
4.1369E+05	4.9444E+02	2.9106E+00	1.0014E+00	4.9749E+05	6.9679E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
6.0000E+01	8.9000E+02	5.6475E-03	1.0014E+00	2.1387E+02	1.6642E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
2.9319E+02	6.2310E+01	1.6399E-02	6.2103E+04	1.5824E+02	9.3315E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
4.2524E-02	1.1216E+02	3.1820E-05	2.6698E+01	5.1917E+02	3.0615E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
3.4235E+06	7.1399E+03	4.4698E-06	5.8969E+00	1.4000E+00	9.9956E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.0435E+06	1.0356E+00	8.0574E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.1858E+04	4.7891E+02	8.6254E-02	4.8175E+05	4.3695E+02	1.7742E+02
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
1.7199E+00	8.6204E+02	1.6736E-04	2.0710E+02	1.4336E+03	5.8208E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.9840E+05	1.3575E+03	2.5572E-05	4.0604E-01	1.3887E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.8239E+05	1.9689E-01	4.6096E-09	6.9160E-01	5.2596E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.3272E+04	4.9423E+02	9.3548E-02	4.9749E+05	7.9556E+03	2.6126E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
1.9250E+00	8.8962E+02	1.8151E-04	2.1387E+02	1.9001E+00	4.7094E-09

TABLE 6. 20-Inch Mach 6 Air Tunnel: $Re_1 = 2.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
8.6185E+05	5.0556E+02	5.9211E+00	1.0030E+00	5.0874E+05	6.7793E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.2500E+02	9.1000E+02	1.1489E-02	1.0030E+00	2.1871E+02	1.6191E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
5.8701E+02	6.3011E+01	3.2480E-02	6.2763E+04	1.5913E+02	9.4443E+02
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
8.5138E-02	1.1342E+02	6.3021E-05	2.6982E+01	5.2208E+02	3.0985E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
6.7831E+06	1.4485E+04	4.5222E-06	5.9349E+00	1.4000E+00	9.9919E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
2.0675E+06	2.1009E+00	8.1517E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.4061E+04	4.8957E+02	1.7120E-01	4.9268E+05	4.4165E+02	1.7918E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
3.4897E+00	8.8122E+02	3.3218E-04	2.1181E+02	1.4490E+03	5.8785E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
1.1817E+06	2.7481E+03	2.5958E-05	4.0570E-01	1.3877E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
3.6018E+05	3.9858E-01	4.6793E-09	6.9171E-01	5.2709E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
2.6924E+04	5.0516E+02	1.8565E-01	5.0874E+05	7.7750E+03	2.6516E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
3.9050E+00	9.0929E+02	3.6023E-04	2.1871E+02	1.8570E+00	4.7799E-09

TABLE 7. 20-Inch Mach 6 Air Tunnel: $Re_1 = 4.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.7237E+06	5.0556E+02	1.1806E+01	1.0061E+00	5.0834E+05	6.5786E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
2.5000E+02	9.1000E+02	2.2907E-02	1.0061E+00	2.1854E+02	1.5712E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.1184E+03	6.2129E+01	6.2816E-02	6.1774E+04	1.5801E+02	9.4506E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.6221E-01	1.1183E+02	1.2188E-04	2.6557E+01	5.1842E+02	3.1006E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.3321E+07	2.8051E+04	4.4566E-06	5.9808E+00	1.4000E+00	9.9830E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
4.0601E+06	4.0685E+00	8.0335E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
4.6598E+04	4.8924E+02	3.3176E-01	4.9233E+05	4.4155E+02	1.7894E+02
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
6.7585E+00	8.8062E+02	6.4371E-04	2.1165E+02	1.4487E+03	5.8707E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
2.2880E+06	5.3113E+03	2.5946E-05	4.0525E-01	1.3879E+00	1.0002E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
6.9737E+05	7.7034E-01	4.6771E-09	6.9172E-01	5.2814E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
5.2132E+04	5.0479E+02	3.5970E-01	5.0834E+05	7.5846E+03	2.6503E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
7.5610E+00	9.0863E+02	6.9793E-04	2.1854E+02	1.8115E+00	4.7775E-09

TABLE 8. 20-Inch Mach 6 Air Tunnel: Re_1 = 5.5 x 10^6 per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
2.5166E+06	5.1944E+02	1.6724E+01	1.0092E+00	5.2249E+05	6.4968E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
3.6500E+02	9.3500E+02	3.2450E-02	1.0092E+00	2.2462E+02	1.5517E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.5992E+03	6.3467E+01	8.7967E-02	6.3069E+04	1.5971E+02	9.5856E+02
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
2.3195E-01	1.1424E+02	1.7068E-04	2.7114E+01	5.2397E+02	3.1449E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.8508E+07	4.0414E+04	4.5560E-06	6.0020E+00	1.4000E+00	9.9788E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
5.6411E+06	5.8615E+00	8.2127E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
6.7146E+04	5.0260E+02	4.6530E-01	5.0607E+05	4.4738E+02	1.8122E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
9.7386E+00	9.0467E+02	9.0283E-04	2.1756E+02	1.4678E+03	5.9455E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
3.1910E+06	7.6403E+03	2.6425E-05	4.0507E-01	1.3866E+00	1.0002E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
9.7262E+05	1.1081E+00	4.7633E-09	6.9187E-01	5.2895E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
7.5105E+04	5.1851E+02	5.0446E-01	5.2249E+05	7.5074E+03	2.6988E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
1.0893E+01	9.3332E+02	9.7882E-04	2.2462E+02	1.7930E+00	4.8648E-09

TABLE 9. 20-Inch Mach 6 Air Tunnel: $Re_1 = 7.5 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
3.2750E+06	5.1944E+02	2.1702E+01	1.0121E+00	5.2222E+05	6.4199E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	(slug/ft^3)		(BTU/lbm)	(BTU/lbm-°R)
4.7500E+02	9.3500E+02	4.2109E-02	1.0121E+00	2.2450E+02	1.5333E+00

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
2.0378E+03	6.3073E+01	1.1287E-01	6.2593E+04	1.5921E+02	9.5878E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
2.9556E-01	1.1353E+02	2.1900E-04	2.6909E+01	5.2234E+02	3.1456E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
2.3906E+07	5.1878E+04	4.5267E-06	6.0221E+00	1.4000E+00	9.9719E-01
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
7.2866E+06	7.5242E+00	8.1599E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
8.6195E+04	5.0237E+02	5.9754E-01	5.0582E+05	4.4732E+02	1.8110E+02
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.2502E+01	9.0426E+02	1.1594E-03	2.1745E+02	1.4676E+03	5.9417E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
4.0966E+06	9.7992E+03	2.6417E-05	4.0486E-01	1.3867E+00	1.0003E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
1.2486E+06	1.4212E+00	4.7619E-09	6.9187E-01	5.2941E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
9.6403E+04	5.1826E+02	6.4778E-01	5.2222E+05	7.4352E+03	2.6979E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
1.3982E+01	9.3287E+02	1.2569E-03	2.2450E+02	1.7758E+00	4.8632E-09

TABLE 10. 15-Inch Mach 6 High Temperature Air Tunnel: $Re_1 = 0.5 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
3.2061E+05	6.4778E+02	1.7221E+00	1.0012E+00	6.5792E+05	7.3236E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
4.6500E+01	1.1660E+03	3.3414E-03	1.0012E+00	2.8284E+02	1.7491E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
2.1684E+02	8.1451E+01	9.2749E-03	8.1330E+04	1.8092E+02	1.0739E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
3.1450E-02	1.4661E+02	1.7996E-05	3.4964E+01	5.9358E+02	3.5232E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.6923E+06	5.3478E+03	5.8856E-06	5.9354E+00	1.4000E+00	9.9992E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
5.1581E+05	7.7564E-01	1.0609E-09	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
8.9017E+03	6.2856E+02	4.9334E-02	6.3754E+05	4.9765E+02	2.0189E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
1.2911E+00	1.1314E+03	9.5723E-05	2.7408E+02	1.6327E+03	6.6237E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
3.2453E+05	1.0054E+03	3.0691E-05	4.0568E-01	1.3725E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
9.8916E+04	1.4582E-01	5.5323E-09	6.9342E-01	5.3191E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
9.9492E+03	6.4778E+02	5.3503E-02	6.5792E+05	8.3208E+03	3.1308E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
1.4430E+00	1.1660E+03	1.0381E-04	2.8284E+02	1.9873E+00	5.6437E-09

TABLE 11. 15-Inch Mach 6 High Temperature Air Tunnel: $Re_1 = 1.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
4.0197E+05	5.3500E+02	2.6136E+00	1.0014E+00	5.3944E+05	7.0577E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
5.8300E+01	9.6300E+02	5.0712E-03	1.0014E+00	2.3191E+02	1.6856E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
2.6857E+02	6.6439E+01	1.4086E-02	6.6263E+04	1.6340E+02	9.7281E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
3.8952E-02	1.1959E+02	2.7331E-05	2.8487E+01	5.3610E+02	3.1916E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
2.8684E+06	6.6651E+03	4.7772E-06	5.9534E+00	1.4000E+00	9.9973E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
8.7428E+05	9.6669E-01	8.6114E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.1075E+04	5.1848E+02	7.4412E-02	5.2249E+05	4.5399E+02	1.8415E+02
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
1.6064E+00	9.3327E+02	1.4438E-04	2.2462E+02	1.4895E+03	6.0416E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.0776E+05	1.2617E+03	2.6987E-05	4.0562E-01	1.3847E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.5477E+05	1.8299E-01	4.8646E-09	6.9204E-01	5.2828E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.2390E+04	5.3487E+02	8.0694E-02	5.3944E+05	8.0569E+03	2.7558E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
1.7970E+00	9.6276E+02	1.5657E-04	2.3191E+02	1.9243E+00	4.9676E-09

TABLE 12. 15-Inch Mach 6 High Temperature Air Tunnel: $Re_1 = 2.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
9.0942E+05	5.3500E+02	5.9022E+00	1.0033E+00	5.3927E+05	6.8225E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.3190E+02	9.6300E+02	1.1452E-02	1.0033E+00	2.3183E+02	1.6294E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
5.5772E+02	6.4811E+01	2.9998E-02	6.4587E+04	1.6139E+02	9.7435E+02
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
8.0891E-02	1.1666E+02	5.8205E-05	2.7766E+01	5.2949E+02	3.1967E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
6.2774E+06	1.4239E+04	4.6561E-06	6.0373E+00	1.4000E+00	9.9935E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.9134E+06	2.0652E+00	8.3931E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.3664E+04	5.1838E+02	1.5902E-01	5.2238E+05	4.5398E+02	1.8381E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
3.4322E+00	9.3308E+02	3.0854E-04	2.2457E+02	1.4894E+03	6.0305E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
1.0832E+06	2.6862E+03	2.6983E-05	4.0488E-01	1.3848E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
3.3016E+05	3.8960E-01	4.8640E-09	6.9204E-01	5.3009E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
2.6462E+04	5.3470E+02	1.7239E-01	5.3927E+05	7.8388E+03	2.7552E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
3.8380E+00	9.6246E+02	3.3449E-04	2.3183E+02	1.8722E+00	4.9666E-09

TABLE 13. 15-Inch Mach 6 High Temperature Air Tunnel: $Re_1 = 3.5 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.5865E+06	5.1111E+02	1.0753E+01	1.0056E+00	5.1417E+05	6.6141E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
2.3010E+02	9.2000E+02	2.0864E-02	1.0056E+00	2.2104E+02	1.5797E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
9.6277E+02	6.1647E+01	5.4489E-02	6.1309E+04	1.5740E+02	9.5170E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.3964E-01	1.1097E+02	1.0573E-04	2.6357E+01	5.1640E+02	3.1224E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.1731E+07	2.4676E+04	4.4207E-06	6.0464E+00	1.4000E+00	9.9846E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
3.5755E+06	3.5789E+00	7.9687E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
4.0998E+04	4.9478E+02	2.8862E-01	4.9803E+05	4.4395E+02	1.7967E+02
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
5.9462E+00	8.9060E+02	5.6001E-04	2.1410E+02	1.4565E+03	5.8948E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
1.9834E+06	4.6587E+03	2.6145E-05	4.0472E-01	1.3873E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
6.0454E+05	6.7568E-01	4.7130E-09	6.9178E-01	5.2968E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
4.5850E+04	5.1044E+02	3.1287E-01	5.1417E+05	7.6329E+03	2.6703E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
6.6500E+00	9.1880E+02	6.0706E-04	2.2104E+02	1.8230E+00	4.8136E-09

TABLE 14. 15-Inch Mach 6 High Temperature Air Tunnel: $Re_1 = 5.0 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
2.3118E+06	5.1389E+02	1.5542E+01	1.0083E+00	5.1677E+05	6.5103E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	(slug/ft^3)		(BTU/lbm)	(BTU/lbm-°R)
3.3530E+02	9.2500E+02	3.0157E-02	1.0083E+00	2.2216E+02	1.5549E+00

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.3730E+03	6.1600E+01	7.7821E-02	6.1182E+04	1.5734E+02	9.5455E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.9914E-01	1.1088E+02	1.5100E-04	2.6302E+01	5.1621E+02	3.1317E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
1.6817E+07	3.5454E+04	4.4172E-06	6.0668E+00	1.4000E+00	9.9779E-01
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
5.1258E+06	5.1422E+00	7.9625E-10	6.9034E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
5.8908E+04	4.9725E+02	4.1262E-01	5.0056E+05	4.4506E+02	1.8003E+02
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
8.5438E+00	8.9504E+02	8.0061E-04	2.1519E+02	1.4602E+03	5.9065E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
2.8316E+06	6.6868E+03	2.6234E-05	4.0451E-01	1.3871E+00	1.0002E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
8.6308E+05	9.6983E-01	4.7289E-09	6.9181E-01	5.3022E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
6.5873E+04	5.1297E+02	4.4725E-01	5.1677E+05	7.5340E+03	2.6793E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
9.5540E+00	9.2334E+02	8.6780E-04	2.2216E+02	1.7994E+00	4.8297E-09

TABLE 15. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.04 \times 10^6$ per foot operating point

<u>Reservoir Stagnation Conditions</u>

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
5.9985E+05	6.2444E+02	1.0143E+01	1.0024E+00	4.2087E+05	3.4056E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	($slug/ft^3$)		(BTU/lbm)	(BTU/lbm-°R)
8.7000E+01	1.1240E+03	1.9681E-02	1.0024E+00	1.8093E+02	8.1337E-01

<u>Freestream Conditions</u>

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
2.7563E+01	1.7754E+02	1.6433E-03	6.1470E+04	1.4373E+02	8.4782E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(ft/sec)	(ft/sec)
3.9977E-03	3.1956E+02	3.1885E-06	2.6426E+01	4.7155E+02	2.7816E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
1.3110E+05	5.9060E+02	1.0627E-05	5.8987E+00	1.2316E+00	1.0000E+00
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
3.9958E+04	8.5658E-02	1.9157E-09	6.9069E-01		

<u>Test Section Post Normal-Shock Static Conditions</u>

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.1057E+03	6.2139E+02	1.8834E-02	4.1813E+05	2.5451E+02	7.3973E+01
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.6037E-01	1.1185E+03	3.6544E-05	1.7976E+02	8.3501E+02	2.4269E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
4.4798E+04	5.1530E+01	3.1100E-05	2.9065E-01	1.1034E+00	1.0000E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
1.3655E+04	7.4737E-03	5.6060E-09	7.6008E-01	1.1461E+01	

<u>Test Section Post Normal-Shock Static Conditions</u>

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
1.1583E+03	6.2410E+02	1.9645E-02	4.2087E+05	3.9963E+03	3.1198E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
1.6800E-01	1.1234E+03	3.8117E-05	1.8093E+02	9.5444E-01	5.6237E-09

TABLE 16. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.05 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
7.3774E+05	6.2722E+02	1.2413E+01	1.0030E+00	4.2360E+05	3.3903E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.0700E+02	1.1290E+03	2.4084E-02	1.0030E+00	1.8211E+02	8.0973E-01

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
3.2198E+01	1.7734E+02	1.9217E-03	6.1373E+04	1.4366E+02	8.5115E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
4.6699E-03	3.1922E+02	3.7287E-06	2.6384E+01	4.7133E+02	2.7925E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.5408E+05	6.9610E+02	1.0616E-05	5.9247E+00	1.2318E+00	1.0000E+00
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
4.6964E+04	1.0096E-01	1.9136E-09	6.9061E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.3034E+03	6.2409E+02	2.2105E-02	4.2087E+05	2.5505E+02	7.3996E+01
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
1.8904E-01	1.1234E+03	4.2890E-05	1.8093E+02	8.3676E+02	2.4277E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.2429E+04	6.0516E+01	3.1198E-05	2.9013E-01	1.1032E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.5980E+04	8.7770E-03	5.6237E-09	7.6016E-01	1.1503E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.3652E+03	6.2680E+02	2.3053E-02	4.2360E+05	3.9851E+03	3.1296E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
1.9800E-01	1.1282E+03	4.4730E-05	1.8211E+02	9.5178E-01	5.6414E-09

TABLE 17. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.07 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.0756E+06	6.2722E+02	1.8074E+01	1.0043E+00	4.2341E+05	3.3543E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.5600E+02	1.1290E+03	3.5069E-02	1.0043E+00	1.8202E+02	8.0112E-01

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
4.3624E+01	1.7475E+02	2.6423E-03	6.0076E+04	1.4276E+02	8.5245E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
6.3271E-03	3.1455E+02	5.1269E-06	2.5827E+01	4.6836E+02	2.7967E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
2.1535E+05	9.6004E+02	1.0459E-05	5.9714E+00	1.2344E+00	1.0000E+00
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
6.5640E+04	1.3924E-01	1.8854E-09	6.8942E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.7973E+03	6.2391E+02	3.0491E-02	4.2068E+05	2.5501E+02	7.3872E+01
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
2.6068E-01	1.1230E+03	5.9162E-05	1.8085E+02	8.3665E+02	2.4236E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
7.2214E+04	8.3196E+01	3.1191E-05	2.8968E-01	1.1032E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
2.2011E+04	1.2067E-02	5.6225E-09	7.6016E-01	1.1539E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.8823E+03	6.2661E+02	3.1795E-02	4.2341E+05	3.9544E+03	3.1289E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
2.7300E-01	1.1279E+03	6.1692E-05	1.8202E+02	9.4446E-01	5.6401E-09

TABLE 18. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.2 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
3.5301E+06	6.5389E+02	5.6346E+01	1.0141E+00	4.4953E+05	3.2819E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
5.1200E+02	1.1770E+03	1.0933E-01	1.0141E+00	1.9325E+02	7.8382E-01

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.3631E+02	1.8729E+02	7.7035E-03	6.6452E+04	1.4708E+02	8.7531E+02
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.9770E-02	3.3712E+02	1.4947E-05	2.8568E+01	4.8253E+02	2.8717E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
6.0150E+05	2.9511E+03	1.1210E-05	5.9514E+00	1.2225E+00	1.0000E+00
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.8334E+05	4.2801E-01	2.0208E-09	6.9496E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
5.5343E+03	6.4954E+02	9.0182E-02	4.4674E+05	2.6002E+02	7.4770E+01
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
8.0267E-01	1.1692E+03	1.7498E-04	1.9205E+02	8.5309E+02	2.4531E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
2.0999E+05	2.5209E+02	3.2110E-05	2.8756E-01	1.1017E+00	1.0000E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2 / ρ_1	
6.4006E+04	3.6562E-02	5.7882E-09	7.6087E-01	1.1707E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
5.7916E+03	6.5227E+02	9.3981E-02	4.4953E+05	3.8891E+03	3.2207E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
8.4000E-01	1.1741E+03	1.8235E-04	1.9325E+02	9.2886E-01	5.8057E-09

TABLE 19. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.4 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
6.5914E+06	6.4833E+02	1.0480E+02	1.0268E+00	4.4249E+05	3.2109E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	$(slug/ft^3)$		(BTU/lbm)	(BTU/lbm-°R)
9.5600E+02	1.1670E+03	2.0335E-01	1.0268E+00	1.9023E+02	7.6687E-01

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
2.5109E+02	1.8253E+02	1.4560E-02	6.4000E+04	1.4546E+02	8.7004E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	$(slug/ft^3)$	(BTU/lbm)	(ft/sec)	(ft/sec)
3.6417E-02	3.2855E+02	2.8251E-05	2.7514E+01	4.7721E+02	2.8545E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
1.1594E+06	5.5109E+03	1.0927E-05	5.9815E+00	1.2269E+00	1.0000E+00
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
3.5337E+05	7.9928E-01	1.9697E-09	6.9291E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.0329E+04	6.4267E+02	1.7012E-01	4.3972E+05	2.5870E+02	7.4467E+01
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	$(slug/ft^3)$	(BTU/lbm)	(ft/sec)	(ft/sec)
1.4982E+00	1.1568E+03	3.3008E-04	1.8903E+02	8.4874E+02	2.4431E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
3.9754E+05	4.7168E+02	3.1866E-05	2.8786E-01	1.1021E+00	1.0000E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
1.2117E+05	6.8410E-02	5.7441E-09	7.6069E-01	1.1684E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
1.0811E+04	6.4538E+02	1.7730E-01	4.4249E+05	3.8193E+03	3.1963E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	$(slug/ft^3)$	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
1.5680E+00	1.1617E+03	3.4401E-04	1.9023E+02	9.1218E-01	5.7616E-09

TABLE 20. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.6 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
1.0501E+07	6.2833E+02	1.6922E+02	1.0453E+00	4.2004E+05	3.1302E+03
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	(slug/ft^3)		(BTU/lbm)	(BTU/lbm-°R)
1.5230E+03	1.1310E+03	3.2835E-01	1.0453E+00	1.8058E+02	7.4760E-01

Freestream Conditions

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
3.8545E+02	1.6839E+02	2.4229E-02	5.6945E+04	1.4050E+02	8.5217E+02
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
5.5904E-02	3.0310E+02	4.7012E-05	2.4481E+01	4.6095E+02	2.7958E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
2.0496E+06	8.7974E+03	1.0074E-05	6.0653E+00	1.2408E+00	1.0000E+00
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
6.2473E+05	1.2759E+00	1.8159E-09	6.8641E-01		

Test Section Post Normal-Shock Static Conditions

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.6462E+04	6.2060E+02	2.8074E-01	4.1734E+05	2.5438E+02	7.3545E+01
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(ft/sec)	(ft/sec)
2.3876E+00	1.1171E+03	5.4472E-04	1.7941E+02	8.3457E+02	2.4129E+02
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
6.6451E+05	7.5924E+02	3.1071E-05	2.8912E-01	1.1035E+00	1.0001E+00
Re_2	q_2	μ_2	Pr_2	ρ_2/ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
2.0254E+05	1.1012E-01	5.6009E-09	7.6006E-01	1.1587E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
1.7237E+04	6.2328E+02	2.9270E-01	4.2004E+05	3.7398E+03	3.1168E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	(slug/ft^3)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
2.5000E+00	1.1219E+03	5.6792E-04	1.8058E+02	8.9320E-01	5.6184E-09

TABLE 21. 20-Inch Mach 6 CF_4 Tunnel: $Re_1 = 0.7 \times 10^6$ per foot operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.3341E+07	6.4889E+02	2.0442E+02	1.0646E+00	4.4084E+05	3.1389E+03
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ ($slug/ft^3$)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.9350E+03	1.1680E+03	3.9663E-01	1.0646E+00	1.8952E+02	7.4968E-01

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
5.0245E+02	1.8023E+02	2.9508E-02	6.2830E+04	1.4466E+02	8.6950E+02
P_1 (psi)	T_1 (°R)	ρ_1 ($slug/ft^3$)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
7.2874E-02	3.2442E+02	5.7254E-05	2.7011E+01	4.7462E+02	2.8527E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
2.3780E+06	1.1154E+04	1.0789E-05	6.0104E+00	1.2290E+00	1.0000E+00
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
7.2482E+05	1.6178E+00	1.9449E-09	6.9190E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.0903E+04	6.4107E+02	3.4510E-01	4.3808E+05	2.5840E+02	7.4346E+01
P_2 (psi)	T_2 (°R)	ρ_2 ($slug/ft^3$)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
3.0318E+00	1.1539E+03	6.6960E-04	1.8833E+02	8.4777E+02	2.4392E+02
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
8.0660E+05	9.5374E+02	3.1809E-05	2.8772E-01	1.1022E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
2.4585E+05	1.3833E-01	5.7338E-09	7.6065E-01	1.1695E+01	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
2.1877E+04	6.4378E+02	3.5966E-01	4.4084E+05	3.7501E+03	3.1905E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ ($slug/ft^3$)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
3.1730E+00	1.1588E+03	6.9784E-04	1.8952E+02	8.9566E-01	5.7513E-09

TABLE 22. 22-Inch Mach 20 He Tunnel: Re_1 = 4.0 x 10^6 per foot (unheated) operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1}$ - $\Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
3.5439E+06	3.0056E+02	5.5872E+00	1.0160E+00	1.5713E+06	2.4150E+04
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1}$ - $\Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
5.1400E+02	5.4100E+02	1.0841E-02	1.0160E+00	6.7550E+02	5.7677E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	H_1 - $\Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
3.4024E+01	2.9582E+00	5.5380E-03	1.5360E+04	1.0120E+02	1.7640E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	H_1 - $\Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
4.9348E-03	5.3247E+00	1.0745E-05	6.6032E+00	3.3202E+02	5.7876E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.3082E+07	8.6167E+03	7.4679E-07	1.7431E+01	1.6667E+00	9.9983E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
3.9873E+06	1.2497E+00	1.3462E-10	6.6565E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	H_2 - $\Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
1.2916E+04	2.8346E+02	2.1934E-02	1.4721E+06	9.9071E+02	4.4539E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	H_2 - $\Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
1.8733E+00	5.1024E+02	4.2559E-05	6.3286E+02	3.2503E+03	1.4612E+03
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.0364E+05	2.1755E+03	1.9397E-05	4.4956E-01	1.6667E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.5351E+05	3.1553E-01	3.4965E-09	6.6667E-01	3.9607E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2}$ - $\Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
1.5203E+04	3.0256E+02	2.4188E-02	1.5713E+06	3.5507E+04	2.0233E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2}$ - $\Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
2.2050E+00	5.4461E+02	4.6932E-05	6.7550E+02	8.4802E+00	3.6471E-09

TABLE 23. 22-Inch Mach 20 He Tunnel: $Re_1 = 11.0 \times 10^6$ per foot (unheated) operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.0377E+07	3.0389E+02	1.5709E+01	1.0464E+00	1.6090E+06	2.1979E+04
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.5050E+03	5.4700E+02	3.0480E-02	1.0464E+00	6.9171E+02	5.2493E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
6.5985E+01	2.5388E+00	1.2518E-02	1.3179E+04	9.3752E+01	1.7865E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
9.5702E-03	4.5698E+00	2.4288E-05	5.6656E+00	3.0759E+02	5.8613E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
3.5687E+07	1.9976E+04	6.2664E-07	1.9056E+01	1.6667E+00	9.9955E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
1.0877E+07	2.8973E+00	1.1296E-10	6.6627E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.9947E+04	2.9029E+02	4.9656E-02	1.5076E+06	1.0026E+03	4.5036E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
4.3434E+00	5.2252E+02	9.6348E-05	6.4812E+02	3.2895E+03	1.4776E+03
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
1.1353E+06	5.0358E+03	1.9698E-05	4.4918E-01	1.6667E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
3.4604E+05	7.3038E-01	3.5507E-09	6.6667E-01	3.9668E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
3.5239E+04	3.0981E+02	5.4748E-02	1.6090E+06	3.3883E+04	2.0545E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
5.1110E+00	5.5766E+02	1.0623E-04	6.9171E+02	8.0925E+00	3.7035E-09

TABLE 24. 22-Inch Mach 20 He Tunnel: Re_1 = 24.0 x 10^6 per foot (unheated) operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
2.2229E+07	2.9333E+02	3.3030E+01	1.1045E+00	1.5905E+06	2.0221E+04
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
3.2240E+03	5.2800E+02	6.4089E-02	1.1045E+00	6.8375E+02	4.8296E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.1457E+02	2.2575E+00	2.4457E-02	1.1713E+04	8.8407E+01	1.7769E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.6617E-02	4.0635E+00	4.7454E-05	5.0353E+00	2.9005E+02	5.8299E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
7.8734E+07	3.8612E+04	5.5197E-07	2.0100E+01	1.6667E+00	9.9898E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
2.3998E+07	5.6001E+00	9.9498E-11	6.6659E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
5.7885E+04	2.8694E+02	9.7088E-02	1.4903E+06	9.9697E+02	4.4762E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
8.3954E+00	5.1649E+02	1.8838E-04	6.4068E+02	3.2709E+03	1.4686E+03
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
2.2229E+06	9.7264E+03	1.9550E-05	4.4898E-01	1.6666E+00	1.0003E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2 / ρ_1	
6.7755E+05	1.4107E+00	3.5242E-09	6.6666E-01	3.9698E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
6.8107E+04	3.0623E+02	1.0704E-01	1.5905E+06	3.2454E+04	2.0391E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
9.8780E+00	5.5121E+02	2.0768E-04	6.8375E+02	7.7512E+00	3.6756E-09

TABLE 25. 22-Inch Mach 20 He Tunnel: $Re_1 = 2.0 \times 10^6$ per foot (heated) operating point

<u>Reservoir Stagnation Conditions</u>

$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(N/m^2)	(K)	(kg/m^3)		(J/kg)	(J/kg-K)
3.5508E+06	5.2778E+02	3.2104E+00	1.0089E+00	2.7510E+06	2.7069E+04
$P_{0,1}$	$T_{0,1}$	$\rho_{0,1}$	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$	$S_{0,1}$
(psi)	(°R)	($slug/ft^3$)		(BTU/lbm)	(BTU/lbm-°R)
5.1500E+02	9.5000E+02	6.2292E-03	1.0089E+00	1.1826E+03	6.4649E+00

<u>Freestream Conditions</u>

P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
3.4250E+01	5.2031E+00	3.1690E-03	2.7019E+04	1.3421E+02	2.3341E+03
P_1	T_1	ρ_1	$H_1 - \Delta H_{f,0}$	a_1	u_1
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(ft/sec)	(ft/sec)
4.9675E-03	9.3655E+00	6.1489E-06	1.1616E+01	4.4033E+02	7.6577E+03
Re_1	q_1	μ_1	M_1	γ_1	Z_1
(1/m)	(N/m^2)	(kg/m-sec)			
5.5882E+06	8.6323E+03	1.3300E-06	1.7391E+01	1.6667E+00	9.9995E-01
Re_1	q_1	μ_1	Pr_1		
(1/ft)	(psi)	(slug/ft-sec)			
1.7033E+06	1.2520E+00	2.3974E-10	6.6580E-01		

<u>Test Section Post Normal-Shock Static Conditions</u>

P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(m/sec)	(m/sec)
1.2940E+04	4.9628E+02	1.2551E-02	2.5773E+06	1.3108E+03	5.8932E+02
P_2	T_2	ρ_2	$H_2 - \Delta H_{f,0}$	a_2	u_2
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(ft/sec)	(ft/sec)
1.8767E+00	8.9331E+02	2.4353E-05	1.1080E+03	4.3007E+03	1.9335E+03
Re_2	q_2	μ_2	M_2	γ_2	Z_2
(1/m)	(N/m^2)	(kg/m-sec)			
2.6833E+05	2.1795E+03	2.7697E-05	4.4957E-01	1.6667E+00	1.0000E+00
Re_2	q_2	μ_2	Pr_2	ρ_2 / ρ_1	
(1/ft)	(psi)	(slug/ft-sec)			
8.1788E+04	3.1611E-01	4.9927E-09	6.6667E-01	3.9606E+00	

<u>Test Section Post Normal-Shock Stagnation Conditions</u>

$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(N/m^2)	(K)	(kg/m^3)	(J/kg)	(J/kg-K)	(kg/m-sec)
1.5231E+04	5.2972E+02	1.3841E-02	2.7510E+06	3.8411E+04	28891E-05
$P_{0,2}$	$T_{0,2}$	$\rho_{0,2}$	$H_{0,2} - \Delta H_{f,0}$	$S_{0,2}$	$\mu_{0,2}$
(psi)	(°R)	($slug/ft^3$)	(BTU/lbm)	(BTU/lbm-°R)	(slug/ft-sec)
2.2090E+00	9.5350E+02	2.6856E-05	1.1826E+03	9.1739E+00	5.2079E-09

TABLE 26. 22-Inch Mach 20 He Tunnel: Re_1 = 4.0 x 10^6 per foot (heated) operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
1.0280E+07	5.8444E+02	8.2770E+00	1.0230E+00	3.0643E+06	2.5391E+04
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
1.4910E+03	1.0520E+03	1.6060E-02	1.0230E+00	1.3173E+03	6.0643E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
6.6419E+01	4.9097E+00	6.5132E-03	2.5494E+04	1.3037E+02	2.4653E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
9.6331E-03	8.8374E+00	1.2638E-05	1.0960E+01	4.2772E+02	8.0882E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
1.2624E+07	1.9792E+04	1.2719E-06	1.8910E+01	1.6668E+00	9.9990E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
3.8479E+06	2.8706E+00	2.2927E-10	6.6592E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
2.9671E+04	5.5285E+02	2.5835E-02	2.8711E+06	1.3836E+03	6.2152E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
4.3034E+00	9.9514E+02	5.0127E-05	1.2343E+03	4.5393E+03	2.0391E+03
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
5.3731E+05	4.9898E+03	2.9883E-05	4.4921E-01	1.6667E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
1.6377E+05	7.2370E-01	5.3868E-09	6.6667E-01	3.9665E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
3.4915E+04	5.9004E+02	2.8485E-02	3.0643E+06	3.7248E+04	3.1169E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
5.0640E+00	1.0621E+03	5.5269E-05	1.3173E+03	8.8961E+00	5.6185E-09

TABLE 27. 22-Inch Mach 20 He Tunnel: $Re_1 = 8.0 \times 10^6$ per foot (heated) operating point

Reservoir Stagnation Conditions

$P_{0,1}$ (N/m^2)	$T_{0,1}$ (K)	$\rho_{0,1}$ (kg/m^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (J/kg)	$S_{0,1}$ (J/kg-K)
2.2036E+07	5.9889E+02	1.6896E+01	1.0484E+00	3.1729E+06	2.3937E+04
$P_{0,1}$ (psi)	$T_{0,1}$ (°R)	$\rho_{0,1}$ (slug/ft^3)	$Z_{0,1}$	$H_{0,1} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,1}$ (BTU/lbm-°R)
3.1960E+03	1.0780E+03	3.2783E-02	1.0484E+00	1.3640E+03	5.7169E+00

Freestream Conditions

P_1 (N/m^2)	T_1 (K)	ρ_1 (kg/m^3)	$H_1 - \Delta H_{f,0}$ (J/kg)	a_1 (m/sec)	u_1 (m/sec)
1.1783E+02	4.6669E+00	1.2157E-02	2.4231E+04	1.2710E+02	2.5094E+03
P_1 (psi)	T_1 (°R)	ρ_1 (slug/ft^3)	$H_1 - \Delta H_{f,0}$ (BTU/lbm)	a_1 (ft/sec)	u_1 (ft/sec)
1.7090E-02	8.4005E+00	2.3588E-05	1.0417E+01	4.1699E+02	8.2330E+03
Re_1 (1/m)	q_1 (N/m^2)	μ_1 (kg/m-sec)	M_1	γ_1	Z_1
2.5151E+07	3.8278E+04	1.2129E-06	1.9744E+01	1.6670E+00	9.9979E-01
Re_1 (1/ft)	q_1 (psi)	μ_1 (slug/ft-sec)	Pr_1		
7.6662E+06	5.5517E+00	2.1864E-10	6.6608E-01		

Test Section Post Normal-Shock Static Conditions

P_2 (N/m^2)	T_2 (K)	ρ_2 (kg/m^3)	$H_2 - \Delta H_{f,0}$ (J/kg)	a_2 (m/sec)	u_2 (m/sec)
5.7385E+04	5.7245E+02	4.8252E-02	2.9730E+06	1.4080E+03	6.3225E+02
P_2 (psi)	T_2 (°R)	ρ_2 (slug/ft^3)	$H_2 - \Delta H_{f,0}$ (BTU/lbm)	a_2 (ft/sec)	u_2 (ft/sec)
8.3230E+00	1.0304E+03	9.3623E-05	1.2781E+03	4.6193E+03	2.0743E+03
Re_2 (1/m)	q_2 (N/m^2)	μ_2 (kg/m-sec)	M_2	γ_2	Z_2
9.9811E+05	9.6440E+03	3.0565E-05	4.4905E-01	1.6667E+00	1.0001E+00
Re_2 (1/ft)	q_2 (psi)	μ_2 (slug/ft-sec)	Pr_2	ρ_2/ρ_1	
3.0423E+05	1.3987E+00	5.5096E-09	6.6666E-01	3.9691E+00	

Test Section Post Normal-Shock Stagnation Conditions

$P_{0,2}$ (N/m^2)	$T_{0,2}$ (K)	$\rho_{0,2}$ (kg/m^3)	$H_{0,2} - \Delta H_{f,0}$ (J/kg)	$S_{0,2}$ (J/kg-K)	$\mu_{0,2}$ (kg/m-sec)
6.7521E+04	6.1093E+02	5.3197E-02	3.1729E+06	3.6059E+04	3.1879E-05
$P_{0,2}$ (psi)	$T_{0,2}$ (°R)	$\rho_{0,2}$ (slug/ft^3)	$H_{0,2} - \Delta H_{f,0}$ (BTU/lbm)	$S_{0,2}$ (BTU/lbm-°R)	$\mu_{0,2}$ (slug/ft-sec)
9.7930E+00	1.0997E+03	1.0322E-04	1.3640E+03	8.6121E+00	5.7465E-09

APPENDIX - THERMODYNAMIC DATA

Constants required in the equations used to compute real gas thermodynamic properties of air, N_2, He and CF_4 are presented in this appendix. These constants are taken from Refs. (2-5). The virial coefficients required in Eqs. (2) and (31a-d) are listed in Tables I-1 through I-4. Various thermodynamic constants are given in Table I-5, and the coefficients required in Eq. (24) for the calculation of zero-pressure specific heats are listed in Tables I-6 and I–7.

When using these thermodynamic data, it must be remembered that the constants were derived from curve fits to real-gas data. They are applicable for pressures from the saturation curve to 100 MPa, but only for maximum temperatures of between 1500 K and 2000 K (500 K to 700 K for CF_4). More information on the region of applicability of these constants can be found in Refs. (2-5). For high-temperature applications, the thermodynamic data tables from Ref. 13 should be employed.

TABLE I-1. Virial Coefficients for Air

j	$b_{1,j}$	$b_{2,j}$	$b_{3,j}$	$b_{4,j}$
0	+0.366812E+00	+0.140979E+00	-0.790202E-01	+0.313247E+00
1	-0.252712E+00	-0.724337E-01	-0.213427E+00	+0.885714E+03
2	-0.284986E+01	+0.780803E+00	-0.125167E+01	+0.634585E+00
3	+0.360179E+01	-0.143512E+00	-0.164970E+00	-0.162912E+00
4	-0.318665E+01	+0.633134E+00	+0.684822E+00	-0.217973E+00
5	+0.154029E+01	-0.891012E+00	+0.221185E+00	+0.925251E-01
6	-0.260953E+00	+0.582531E-01	+0.634056E-01	+0.893863E-03
7	-0.391073E-01	+0.172908E-01	-	-

j	$b_{5,j}$	$b_{6,j}$	$b_{7,j}$	$b_{8,j}$
0	-0.444978E+00	+0.285780E+00	-0.636588E-01	+0.116375E-03
1	-0.734544E+00	+0.258413E+00	-0.105811E+00	+0.361900E-01
2	+0.199522E-01	+0.749790E-01	-0.345172E-01	-0.195095E-01
3	-0.176007E+00	+0.859487E-01	+0.429817E-01	-0.379583E-02
4	-0.998455E-01	-0.884071E-03	+0.631385E-02	-
5	-0.620965E-01	-	-	-

TABLE I-2. Virial Coefficients for N_2

j	$b_{1,j}$	$b_{2,j}$	$b_{3,j}$	$b_{4,j}$
0	+0.3975526E+00	+0.1855514E+00	-0.2011402E+00	+0.4390253E+00
1	-0.2705628E+00	-0.1251586E+00	+0.2126380E+00	-0.2435610E+00
2	-0.2956163E+01	+0.5964582E+00	-0.8113148E+00	+0.6355942E+00
3	+0.3066081E+01	+0.1284639E+01	-0.1120779E+01	+0.2230845E+01
4	-0.1877000E+01	-0.2557264E+01	+0.3545519E+00	-0.1020368E+01
5	+0.7416446E+00	+0.2063303E+01	+0.4458802E+00	+0.4268763E-01
6	-0.3944179E+00	-0.8252342E+00	+0.1533152E+00	-
7	+0.1301370E+00	-	-	-

j	$b_{5,j}$	$b_{6,j}$	$b_{7,j}$	$b_{8,j}$
0	-0.2895013E+00	+0.2412197E-01	+0.1978643E-01	+0.5228906E-02
1	+0.6526003E-01	+0.4203559E+00	-0.2167127E+00	+0.7813518E-02
2	-0.1179467E+01	+0.3041304E+00	-0.1345965E-01	+0.1870709E-03
3	-0.4640865E+00	+0.9062116E-01	+0.6390886E-01	-0.4644895E-01
4	-0.1429483E+00	+0.1011631E+00	+0.1649284E-01	-0.2800780E-02
5	-0.6222610E-01	-0.1738903E-02	-	-

j	$b_{9,j}$	$b_{10,j}$
0	-0.5215002E-02	+0.7925797E-03
1	+0.1394557E-01	-0.2349711E-02
2	+0.18890 96E-02	-0.2509582E-03
3	+0.3741580E-02	+0.4146276E-03

TABLE I-3a. Virial Coefficients for He ($T < 20$ K)

j	$b_{1,j}$	$b_{2,j}$	$b_{3,j}$	$b_{4,j}$
0	+0.2819155E+00	+0.8462366E-01	+0.4704854E-01	-0.1260754E+00
1	-0.1292457E+01	+0.3001846E+00	-0.5334322E+00	+0.1101237E+01
2	-0.2129594E+00	-0.5251701E+00	+0.3341696E+00	-0.6353332E-01
3	+0.6437906E+00	+0.5410069E+00	+0.8362204E-01	-0.6627022E+00
4	-0.8326190E+00	-0.1832495E+00	+0.4843829E+00	-0.1973173E+00
5	+0.5006948E+00	-0.1714369E+00	-0.3192986E-01	-0.1678553E-01
6	-0.1412233E+00	+0.7279349E-01	+0.3671224E-02	-
7	+0.1488343E-01	-0.8634785E-02	-	-
j	$b_{5,j}$	$b_{6,j}$	$b_{7,j}$	$b_{8,j}$
0	+0.5636224E-01	+0.1531109E-01	-0.1170722E-01	+0.8140690E-03
1	-0.7136530E+00	+0.1095645E+00	+0.4836444E-01	-0.1915444E-01
2	-0.1632410E+00	+0.1901053E+00	-0.5169830E-01	-0.1581469E-03
3	+0.3670216E+00	-0.1029899E+00	+0.1255776E-01	-
4	+0.7594056E-01	-0.1194448E-01	-	-
5	+0.3843195E-02	-	-	-
j	$b_{9,j}$	$b_{10,j}$		
0	+0.3304047E-03	-0.3739834E-04		
1	+0.2581156E-02	-0.1619576E-03		
2	+0.9684371E-03	-		

TABLE I-3b. Virial Coefficients for He ($T \geq 20$ K)

j	$b_{1,j}$	$b_{2,j}$	$b_{3,j}$	$b_{4,j}$
0	+0.1803041E+00	+0.1611295E-01	+0.1042847E+00	-0.1551514E+00
1	+0.1285745E+01	+0.8707625E+00	-0.8700183E+00	+0.7052546E+00
2	-0.2378314E+02	-0.1357183E+01	+0.2815541E+01	-0.1921619E+01
3	+0.9971745E+02	-0.5198535E+01	-0.9708081E+00	+0.2201513E+01
4	-0.1938884E+03	+0.1429547E+02	-0.5541532E+01	-
5	+0.1406779E+03	-	-	-
j	$b_{5,j}$	$b_{6,j}$	$b_{7,j}$	$b_{8,j}$
0	+0.1100556E+00	-0.3927200E-01	+0.6593721E-02	-0.4079607E-03
1	-0.3090680E+00	+0.1145860E+00	-0.2201105E-01	+0.1466608E-02
2	+0.3587898E+00	-0.4085258E-01	+0.4600854E-02	-
3	-0.2586436E+00	-	-	-

TABLE I-4a. Virial Coefficients for CF_4 ($T < 300$ K)

$$b_{1,0} = 0.0$$

TABLE I-4b. Virial Coefficients for CF_4 ($T \geq 300$ K)

j	$b_{1,j}$	$b_{2,j}$	$b_{3,j}$	$b_{4,j}$
0	+0.465412376E+00	-0.683861484E+01	+0.403130439E+02	-0.832210407E+02
1	-0.460830210E-01	+0.424438192E+02	-0.243712705E+03	+0.485824947E+03
2	-0.279065609E+01	-0.101485246E+03	+0.585324920E+03	-0.120295695E+04
3	+0.191861073E+01	+0.101860686E+03	-0.585470766E+03	+0.122909822E+04
4	-0.695307991E+00	-0.362080449E+02	+0.206929314E+03	-0.437477850E+03

j	$b_{5,j}$	$b_{6,j}$	$b_{7,j}$	$b_{8,j}$
0	+0.884003700E+02	-0.602127680E+02	+0.315203148E+02	-0.124208458E+02
1	-0.455461859E+03	+0.222584375E+03	-0.616670331E+02	+0.119804952E+02
2	+0.118356341E+04	-0.610970536E+03	+0.167200162E+03	-0.219631820E+02
3	-0.125926799E+04	+0.693662147E+03	-0.210325216E+03	+0.330114834E+02
4	+0.456436501E+03	-0.258255436E+03	0.810086172E+02	-0.132765311E+02

j	$b_{9,j}$	$b_{10,j}$
0	+0.300137179E+01	-0.311203418E+00
1	-0.226476800E+01	+0.272703261E+00
2	+0.953533444E+00	-
3	-0.208045601E+01	-
4	+0.887624065E+00	-

TABLE I-5. Thermodynamic Constants

Constant	Air	N_2	He	CF_4
σ(Å)	3.689	3.749	-	-
T^{ε} (K)	84	79.8	-	-
p_{CR} (MPa)	3.766	3.400	2.2746	3.745
T_{CR} (K)	132.5	126.2	5.190	227.5
ρ_{CR} (kg/m^3)	316.5	313.1	69.64	629.7
$\Delta h_{f,0}$ (J/kg)	253.4E+03	247.6E+03	14.704E+03	197.50E+03
h_{ref}/RT_{ref}	3.48115	3.4902	2.5000	2.875
$\Delta s_{f,0}$ (J/kg-K)	0	0	0	0
s_{ref}/R	20.0824	19.2040	12.4284	25.1800
W (g/g-mol)	28.9644	28.0134	4.0026	88.0046

TABLE I-6. α Coefficients for Specific Heat Curve Fits

Constant	Air	N_2	He	CF_4
α_0	+0.661738E+01	+0.113129E+02	+0.250000E+01	+0.393879867E+01
α_1	-0.105885E+01	-0.215960E+01	-	+0.236720580E+01
α_2	+0.201650E+00	+0.352761E+00	-	-0.228381967E+00
α_3	-0.196930E-01	-0.321705E-01	-	+0.798491855E-02
α_4	+0.106460E-02	+0.167690E-02	-	-
α_5	-0.303284E-04	-0.467965E-04	-	-
α_6	+0.355861E-06	+0.542603E-06	-	-

TABLE I-7. β Coefficients for Specific Heat Curve Fits

Constant	Air	N_2	He	CF_4
β_1	-0.549169E+01	-0.174654E+02	-	-0.808631829E+01
β_2	+0.585171E+01	+0.246205E+02	-	+0.939836215E+01
β_3	-0.372865E+01	-0.217731E+02	-	-0.322414015E+01
β_4	+0.133981E+01	+0.116418E+02	-	-
β_5	-0.233758E+00	-0.342122E+01	-	-
β_6	+0.125718E-01	+0.422296E-00	-	-

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1996	Contractor Report

4. TITLE AND SUBTITLE
Real-Gas Flow Properties for NASA Langley Research Center Aerothermodynamic Facilities Complex Wind Tunnels

5. FUNDING NUMBERS
Grants NAG1-1663
NASw-1331

WU 242-80-01-01

6. AUTHOR(S)
Brian R. Hollis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
North Carolina State University
Department of Mechanical and Aerospace Engineering
Raleigh, NC 27695

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA CR-4755

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Harris H. Hamilton II

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 34

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A computational algorithm has been developed which can be employed to determine the flow properties of an arbitrary real (virial) gas in a wind tunnel. A multiple-coefficient virial gas equation of state and the assumption of isentropic flow are used to model the gas and to compute flow properties throughout the wind tunnel. This algorithm has been used to calculate flow properties for the wind tunnels of the Aerothermodynamics Facilities Complex at the NASA Langley Research Center, in which air, CF_4, He, and N_2 are employed as test gases. The algorithm is detailed in this paper and sample results are presented for each of the Aerothermodynamic Facilities Complex wind tunnels.

14. SUBJECT TERMS
Wind Tunnels
Thermodynamic Properties
Real Gas

15. NUMBER OF PAGES
64

16. PRICE CODE
A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited